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THE ECONOMIC VALUE OF PACIFIC COAST KELPS

BY

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THE ECONOMIC VALUE OF PACIFIC COAST KELPS

BY

JOHN S. BURD*

A great deal has been written in the past few years in reference to the commercial utilization of certain seaweeds or kelps growing in the waters of the Pacific Coast of North America. Several species, notable for their extraordinary size and commonly called "giant kelps," are to be found in scattered beds along the coast of California. Of these, the kelp known as *Nereocystis Luetkeana* occurs in occasional beds from the northern boundary of the state to Point Conception, the more abundant stands south of that point consisting largely of *Macrocystis pyrifera.*

The present paper embodies a portion of the results obtained in this laboratory in an extensive series of studies on the chemistry of kelps. Some of these studies have more scientific interest than immediate practical importance. It is thought desirable to reserve these latter for publication elsewhere and to consider here only such data and conclusions as have bearing on the commercial utilization of kelp. The results presented hereafter furnish the following general conclusions:

1. The giant kelps contain potassium, iodine and nitrogen in amounts which will possibly justify commercial recovery.

2. Estimates of potash yields which are based on analyses of leaves and stems and do not take into account the larger proportion of leaf to stem in the growing plant are likely to be higher than can be expected in the average run of commercial recovery.

3. Exact determinations of the moisture content of the more common of the giant kelps, here presented for the first time, show that weight for weight of fresh kelp *Macrocystis pyrifera* contains more of each important constituent than does *Nereocystis Luetkeana.*

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* Grateful acknowledgment is made to Professor Wm. A. Setchell of the University of California for helpful advice and assistance in collecting material; to Professor Frank M. McFarland of the Leland Stanford Junior University for the use of the Marine Biological Laboratory at Pacific Grove, and to Dr. W. W. McKay of the United States Marine Hospital Service for the use of wharf and drying sheds at San Diego. Acknowledgment is also made to the following members of this staff: G. R. Stewart, D. R. Hoagland, P. L. Hibbard, and W. H. Dore for the large amount of analytical work and other assistance involved in this study.

4. The efflorescence of potash salts when kelps are slowly dried cannot be utilized to advantage in the commercial preparation of potash if a large yield of high grade salts is desired.

5. No technological difficulties are involved in preparing high grade potash salts and iodine from kelp, but exact costs of production can only be arrived at from data obtained on a large scale, as in actual factory practice. Apparently, however, extraordinary profits are not to be expected owing to the limited value of the product and the large amount of manipulation involved in the various methods of recovery.

6. Air-dried kelp will furnish a low grade potash fertilizer comparable to kainit and containing in addition over 1 per cent of nitrogen and 50 per cent of organic matter capable of furnishing humus to the soil.

7. Objections to the use of dried kelp because of the presence of sodium and chlorine are untenable, because this material contains less sodium and chlorine than most of the commercial potash salts now being used and is but little inferior in this respect to the highest grades of muriate.

The pioneer work of Balch[1] has shown that the giant kelps of the Pacific Coast, notably *Macrocystis pyrifera, Pelagophycus porra,* and *Nereocystis Luetkeana,* contain extraordinary quantities of potassium salts, largely in the form of potassium chloride. Turrentine[2] and his co-workers[3] have much enlarged our information in this field and presented valuable data as to the magnitude and variations in composition of these and other species of marine algae. Based on this work, some interesting speculations have been published as to the possibility of founding an industry for the recovery of potash salts, iodine and other substances from kelp. The affirmative view[4] expressed by some of these has not been without contradiction,[5] and it is evident that further information is essential to a determination of the economic status of these curious plants.

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[1] On the Chemistry of Certain Algae of the Pacific Coast, by David M. Balch, Journal of Industrial and Engineering Chemistry, Vol. 1, No. 12, December, 1909.

[2] The Composition of the Pacific Kelps, by J. W. Turrentine, Journal of Industrial and Engineering Chemistry, Vol. 4, No. 6, June, 1912.

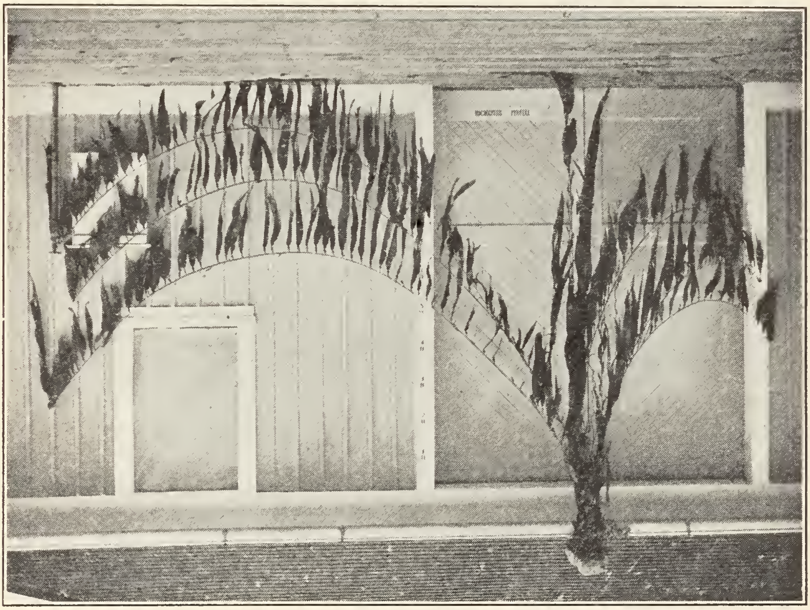
[3] Analyses of Certain of the Pacific Coast Kelps, by E. G. Parker and J. R. Lindemuth, Journal of Industrial and Engineering Chemistry, Vol. 5, No. 4, April, 1913.

[4] Potash from the Pacific Kelps, by F. K. Cameron, Journal of Industrial and Engineering Chemistry, Vol. 4, No. 2, February, 1912.

[5] The Business Aspect of the Kelp Proposition, by F. P. Dewey, Journal of Industrial and Engineering Chemistry, Vol. 4, No. 4, April, 1912; Seaweed, Potash and Iodine, a Criticism, by Henrik Knudsen, Journal of Industrial and Engineering Chemistry, Vol. 4, No. 8, August, 1912.

A careful search of the literature indicates that the kelps from which the most is to be expected are those heretofore mentioned. In collecting material for this investigation stations were established at San Diego and Pacific Grove, as being both representative and convenient. All photographing, measurement of dimensions and weights and preliminary drying of plants was conducted in the field. The observations of G. R. Stewart, who performed the field work, confirm those of other observers in that for Southern California the *Macrocystis pyrifera* is the most abundant species, *Pelagophycus porra* being "only sparsely distributed over limited areas";[6] while for the central Californian coast both *Macrocystis* and *Nereocystis* occur in beds of considerable size.

The botanical structure, habitat, method of reproduction, etc., have been described for all of the important species of kelp.[7] The photographs herewith will perhaps illustrate better than further description

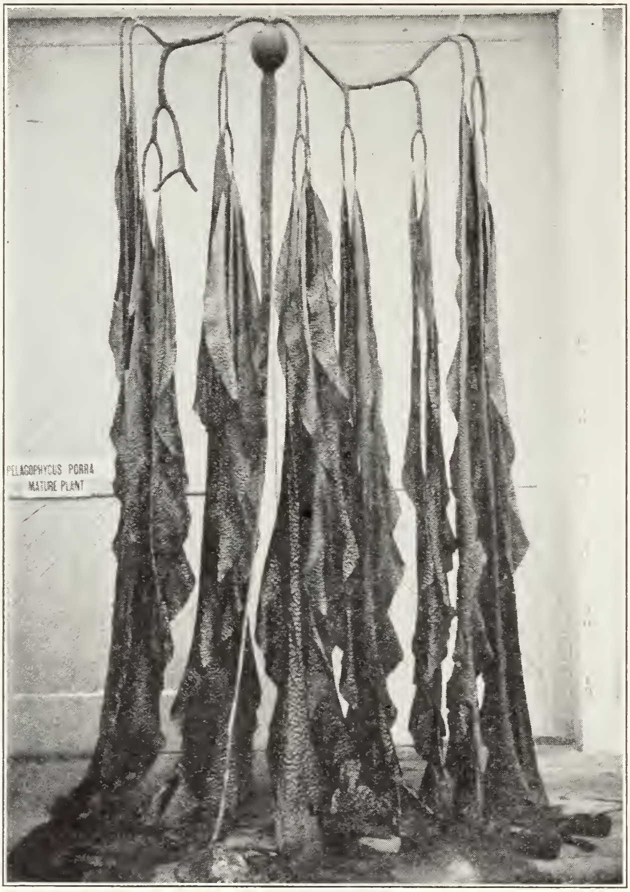


Macrocystis pyrifera, complete plant of small size, holdfast attached to rock; sample taken off Point Loma at the mouth of San Diego Bay. (Photograph inverted to show habit of growth.)

[6] The Kelps of the Southern Californian Coast, by W. C. Crandall, Fertilizer Resources of the United States, Senate Document No. 190, p. 211.

[7] The Kelps of the United States and Alaska, by Wm. A. Setchell, Fertilizer Resources of the United States, Senate Document No. 190; Ecological and Economic Notes on Puget Sound Kelps, by George B. Rigg, Fertilizer Resources of the United States, Senate Document No. 190; The Kelps of the Central Californian Coast, by Frank M. McFarland, Fertilizer Resources of the United States, Senate Document No. 190.

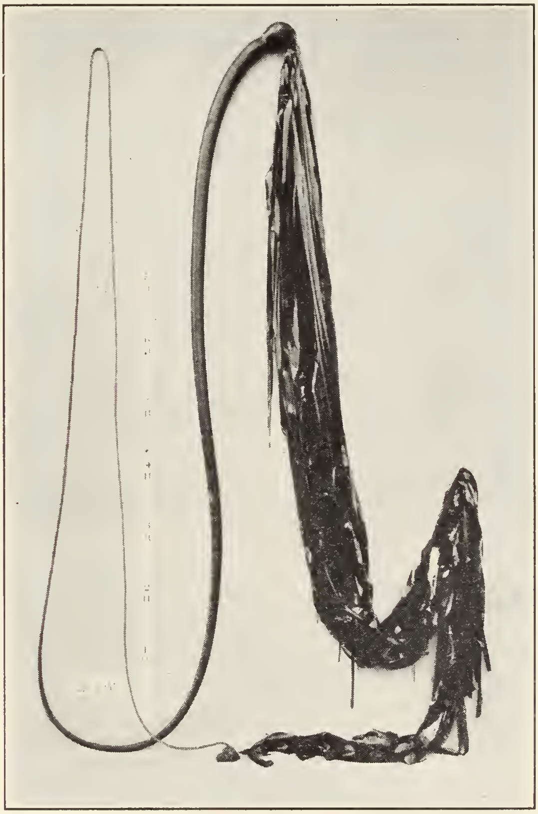
the mode of growth and suggest some of the problems to be expected in harvesting the plants. It should be noted that all of these are attached to the bed of the ocean, usually on rocks, and that the entire plant is only harvested with difficulty. In *Pelagophycus* and *Nereocystis* the pneumatocyst (hollow bulb and adjacent portion of stem) tend to float and support the leaves near the surface of the water. In



Pelagophycus porra, mature plant taken near Point Loma.

Macrocystis, however, the arrangement of the leaves and relatively smaller bulbs with reference to the stems is such that a considerable proportion of the plant will always be beyond the depth of convenient harvesting. In this work the entire plant was harvested wherever possible and divided into so-called "harvestable" and "non-harvestable" portions. The former comprising all of that portion within twelve feet of the surface of the water, and the latter including the

remainder of the plant, exclusive of holdfast, hapteres and adhering leaves. Further, the leaves (laminae) were carefully severed from the stemlike portions (stipes and pneumatocysts). Specimens were thus segregated into four portions, designated herein as harvestable leaves, harvestable stems, non-harvestable leaves and non-harvestable stems. The advantage of this procedure is that all data subsequently



Nereocystis Luetkeana, complete old plant, taken off Point Cypress.

obtained may be computed either to structurally distinct portions of the plant (leaves and stems) or to economically distinct portions (harvestable and non-harvestable).

RELATIVE PROPORTIONS OF LEAVES AND STEMS IN FRESH KELP

Macrocystis pyrifera.—The samples of this species varied in weight (exclusive of holdfast) from 27 to 300 pounds, and 25 to 80 per cent of the entire plant was harvestable. In general, the greater percentages of harvestable portion are to be found in the larger plants. Of

TABLE 1

RELATIVE PROPORTIONS OF LEAVES, STEMS, ETC., IN FRESH KELP

No. of Plant	Date of collection 1913	Variety of Kelp	General location of Plants	Harvestable portion*: Weight of leaves, lbs.	Harvestable portion*: Weight of stems, lbs.	Non-harvestable portion: Weight of leaves, lbs.	Non-harvestable portion: Weight of stems, lbs.	Weight of entire plant exclusive of hold-fast, lbs.	Weight of hold-fast and adhering leaves, lbs.	Harvestable portion: Per cent of leaves	Harvestable portion: Per cent of stems	Non-harvestable portion: Per cent of leaves	Non-harvestable portion: Per cent of stems	Per cent of harvestable portion in entire plant exclusive of hold-fast
1	Aug. 30	Macrocystis pyrifera	Pt. Loma bed	12.25	5.0	9.0	10.0	36.25	19.5	71.02	28.98	47.37	52.63	47.59
2	Aug. 30	Macrocystis pyrifera	Pt. Loma bed	139.25	103.25	20.75	35.0	298.25	137.0	57.42	42.58	37.22	62.78	81.31
3	Sept. 1	Macrocystis pyrifera	Pt. Loma bed	42.5	20.50	33.75	23.75	120.5	missing	67.46	32.54	58.70	41.30	52.28
4	Sept. 2	Macrocystis pyrifera	Pt. Loma bed	12.0	4.75	32.5	30.0	79.25	missing	71.64	28.36	52.00	48.00	21.14
5	Sept. 2	Macrocystis pyrifera	Pt. Loma bed	4.5	2.5	11.5	9.0	27.50	missing	64.29	35.71	56.10	43.90	25.45
6	Sept. 2	Macrocystis pyrifera	Pt. Loma bed	16.75	6.5	45.5	24.0	92.75	missing	72.04	27.96	65.47	34.53	25.07
7	Sept. 3	Macrocystis pyrifera	Pt. Loma bed	10.0	4.75	......	......	......	missing	67.80	32.20	......	......	......
8	Sept. 3	Macrocystis pyrifera	Pt. Loma bed	8.25	2.75	......	......	......	missing	75.00	25.00	......	......	......
9	Sept. 3	Macrocystis pyrifera	Pt. Loma bed	13.25	9.0	8.25	24.5	55.0	23.75	59.55	40.45	25.19	74.81	40.45
10	Sept. 4	Macrocystis pyrifera	La Jolla bed	26.0	11.25	......	......	......	missing	69.80	30.20	......	......	......
11	Sept. 4	Macrocystis pyrifera	La Jolla bed	31.25	11.5	......	......	......	missing	73.10	26.90	......	......	......
12	Sept. 4	Macrocystis pyrifera	La Jolla bed	26.25	11.25	......	......	......	missing	69.54	30.46	......	......	......
13	Sept. 4	Macrocystis pyrifera	La Jolla bed	20.25	11.25	......	......	......	missing	64.29	35.71	......	......	......
1	Sept. 1	Pelagophycus porra	Pt. Loma bed	13.25	10.0	0.0	2.1	25.35	negligible	56.99	43.01	0.0	100.0	91.72
4	Sept. 1	Pelagophycus porra	Pt. Loma bed	9.0	6.5	0.0	2.7	18.20	negligible	58.06	41.94	0.0	100.0	85.17
5	Sept. 1	Pelagophycus porra	Pt. Loma bed	8.0	5.75	0.0	2.4	16.15	negligible	58.18	41.82	0.0	100.0	85.14
6	Sept. 2	Pelagophycus porra	Pt. Loma bed	45.5	22.25	0.0	4.0	71.75	negligible	67.16	32.84	0.0	100.0	94.43
7	Sept. 2	Pelagophycus porra	Pt. Loma bed	51.0	19.0	0.0	3.0	73.0	negligible	72.86	27.14	0.0	100.0	95.90
1	Oct. 17	Nereocystis Luetkeana	Near Pt. Cypress	34.0	25.25	0.0	negligible	......	negligible	57.39	42.61	......	......	......
2	Oct. 17	Nereocystis Luetkeana	Bet. Pt. Joe and Pt. Cypress	28.15	12.15	0.0	negligible	......	negligible	69.85	30.15	......	......	......

TABLE 1—(*Concluded*)

No. of Plant	Date of collection 1913	Variety of Kelp	General location of Plants	Harvestable portion*: Weight of leaves, lbs.	Harvestable portion*: Weight of stems, lbs.	Non-harvestable portion: Weight of leaves, lbs.	Non-harvestable portion: Weight of stems, lbs.	Weight of entire plant exclusive of hold-fast, lbs.	Weight of hold-fast and adhering leaves, lbs.	Harvestable portion: Per cent of leaves	Harvestable portion: Per cent of stems	Non-harvestable portion: Per cent of leaves	Non-harvestable portion: Per cent of stems	Per cent of harvestable portion in entire plant exclusive of hold-fast
3	Oct. 17	Nereocystis Luetkeana	S. of Pt. Cypress	41.15	15.65	0.0	negligible	....	negligible	72.45	27.55	....	....	....
4	Oct. 17	Nereocystis Luetkeana	Bet. Pt. Joe and Pt. Cypress	7.9	7.9	0.0	negligible	....	negligible	50.00	50.00	....	....	....
5	Oct. 17	Nereocystis Luetkeana	Carmel Bay	5.65	9.15	0.0	negligible	....	negligible	38.18	61.82	....	....	....
6	Oct. 17	Nereocystis Luetkeana	Bet. Pt. Joe and Pt. Cypress	32.65	12.15	0.0	negligible	....	negligible	72.88	27.12	....	....	....
7	Oct. 18	Nereocystis Luetkeana	Opp. Pt. Pinos Light	28.4	10.15	0.0	negligible	....	negligible	73.66	26.34	....	....	....
8	Oct. 18	Nereocystis Luetkeana	N. of Pt. Pinos Light	8.9	8.4	0.0	negligible	....	negligible	51.45	48.55	....	....	....
9	Oct. 18	Nereocystis Luetkeana	N. of Pt. Joe	18.4	10.65	0.0	negligible	....	negligible	63.34	36.66	....	....	....
10	Oct. 18	Nereocystis Luetkeana	S. of Pt. Joe	20.4	8.9	0.0	negligible	....	negligible	69.62	30.38	....	....	....
11	Oct. 18	Nereocystis Luetkeana	S. of Pt. Pinos	18.15	5.4	0.0	negligible	....	negligible	77.07	22.93	....	....	....
12	Oct. 18	Nereocystis Luetkeana	Opp. Pt. Pinos Light	17.4	8.4	0.0	negligible	....	negligible	67.44	32.56	....	....	....
13	Oct. 18	Nereocystis Luetkeana	Opp. Pt. Joe	29.4	15.15	0.0	negligible	....	negligible	66.00	34.00	....	....	....
14	Oct. 18	Macrocystis pyrifera	Off Pt. Pinos Light	33.0	9.25	....	......	....	missing	78.11	21.89	....	....	....
15	Oct. 18	Macrocystis pyrifera	Off Pt. Pinos Light	71.0	26.25	....	......	....	missing	73.01	26.99	....	....	....
16	Oct. 18	Macrocystis pyrifera	N. end Pt. Pinos bed	28.0	27.75	....	......	....	missing	50.22	49.78	....	....	....
17	Oct. 20	Macrocystis pyrifera	Pt. Pinos bed	41.0	26.65	13.25	17.4	98.30	missing	60.60	39.40	43.23	56.77	68.82
18	Oct. 20	Macrocystis pyrifera	Opp. Del Monte	30.0	7.9	14.25	10.65	62.80	missing	79.16	20.84	57.23	42.77	60.35

* The harvestable portion of Macrocystis and Pelagophycus consisted of the floating surface growth and also the leaves and stems to a depth of 12 feet, this being considered the extreme depth of commercial cutting. With Nereocystis the entire plant, except a small portion of the lower stem, was sampled.

the harvestable portion, from 60 to 75 per cent consisted of leaves. It will be seen subsequently that the potash content of the leaves of all species is much inferior to that of the stems. Some of the estimates of the potash content of kelps have not taken into account the disproportion between the amounts of leaf and stem and have tended to assign values to the plants as a whole which they do not possess.

Pelagophycus porra.—These plants varied in weight from 16 to 71 pounds, from 85 to 96 per cent of the entire plant being harvestable. Of the harvestable portion, from 57 to 73 per cent consisted of leaves.

Nereocystis Luetkeana.—It was not found possible to harvest entire plants, but practically all was obtained in each case, the very small stipe anchoring the plant to the ocean bed being negligible and probably not amounting to more than 1 or 2 per cent by weight. The maximum weight of any plant was 56 pounds at the season sampled (fall). Of the harvestable portion, from 50 to 77 per cent consisted of leaves.

MAJOR ECONOMIC CONSTITUENTS OF KELP

While a considerable number of partial analyses of the various parts and of entire kelps have been published heretofore, the methods of sampling and arrangement of data have not been such as to justify exact conclusions as to what is to be expected in the average run of commercial recovery. It is believed that the results here reported are free from this objection owing to the extreme precautions which were taken in sampling and to the fact that the initial weighings were made almost immediately after harvesting.

Sampling of Kelps.—In this operation plants as drawn from the water were immediately covered with a tarpaulin to prevent evaporation. As soon as a sufficient number of specimens had been collected they were taken ashore, weighed, placed on a smooth floor under cover, measured and dissected into the four portions heretofore mentioned. The samples for analysis were obtained by cutting up each portion into small segments, mixing and withdrawing grab samples. Weighed portions of each sample were air dried, placed in glass containers, sealed and forwarded to the laboratory. Samples in practically all cases consisted of two kilograms of material. All were dried immediately on reaching the laboratory, usually within two or three days after taking from the water. In no case was any putrefaction observed.

Character of Data.—The results shown in Table 2 indicate that kelps, like land plants, are subject to variation in composition, and it may be contended that conclusions as to the average composition should be based on a very much larger number of specimens than represented

TABLE 2

COMPOSITION OF LEAVES AND STEMS (HARVESTABLE AND NON-HARVESTABLE PORTIONS)

Laboratory number	General description of Sample	Per cent of Water in air-dried Kelp	Composition of oven-dried samples (All data averages of two closely agreeing determinations)					Composition of water-free samples (Computed)				Composition of fresh material (Computed)				
			Per cent of Moisture	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Per cent of Moisture	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine
1.1*	Macrocystis pyrifera, No. 1, harvestable leaves	....	2.19	1.69	.93	10.03	.25	1.73	.95	10.25	.26	83.82	.28	.15	1.66	.04
1.2	Macrocystis pyrifera, No. 1, harvestable stems	....	3.81	.98	.69	18.92	.09	1.02	.72	19.67	.09	88.83	.11	.08	2.20	.01
1.3	Macrocystis pyrifera, No. 1, non-harvestable leaves	....	1.49	2.39	1.10	10.38	.41	2.43	1.12	10.54	.41	84.48	.38	.17	1.64	.06
1.4	Macrocystis pyrifera, No. 1, non-harvestable stems	....	2.47	1.16	.73	14.06	.13	1.19	.75	14.42	.13	86.90	.16	.10	1.89	.02
2.1	Macrocystis pyrifera, No. 2, harvestable leaves	....	1.79	1.32	.70	11.90	.28	1.34	.71	12.12	.29	85.18	.20	.11	1.80	.04
2.2	Macrocystis pyrifera, No. 2, harvestable stems	....	3.70	.76	.53	19.99	.19	.79	.55	20.76	.19	88.98	.09	.06	2.29	.02
2.3	Macrocystis pyrifera, No. 2, non-harvestable leaves	....	2.11	3.47	2.24	11.90	.56	3.55	2.29	12.16	.57	86.63	.47	.31	1.63	.08
2.4	Macrocystis pyrifera, No. 2, non-harvestable stems	....	4.13	1.08	.77	13.06	.30	1.13	.80	13.62	.31	87.42	.14	.10	1.71	.04
3.1	Macrocystis pyrifera, No. 3, harvestable leaves	....	1.92	.96	.57	14.05	.21	.98	.58	14.33	.21	84.68	.15	.09	2.20	.03
3.2	Macrocystis pyrifera, No. 3, harvestable stems	....	4.07	.40	.40	17.84	.08	.42	.42	18.60	.08	86.75	.06	.06	2.46	.01
3.3	Macrocystis pyrifera, No. 3, non-harvestable stems	....	1.19	.96	.44	14.72	.28	.97	.45	14.90	.28	86.10	.13	.06	2.07	.04
3.4	Macrocystis pyrifera, No. 3, non-harvestable stems	....	3.67	.47	.43	18.86	.12	.49	.45	19.58	.12	88.40	.06	.05	2.27	.01
4.1	Macrocystis pyrifera, No. 4, harvestable leaves	....	2.96	2.08	.92	11.31	.19	2.14	.95	11.65	.20	87.96	.26	.11	1.40	.02
4.2	Macrocystis pyrifera, No. 4, harvestable stems	....	3.62	1.25	.65	20.70	.14	1.30	.67	21.48	.14	88.73	.15	.08	2.42	.02

TABLE 2—(*Continued*)

Laboratory number	General description of Sample	Per cent of Water in air-dried Kelp	Composition of oven-dried samples (All data averages of two closely agreeing determinations)					Composition of water-free samples (Computed)				Composition of fresh material (Computed)				
			Per cent of Moisture	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Per cent of Moisture	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine
4.3	Macrocystis pyrifera, No. 4, non-harvestable leaves	....	2.79	2.80	1.12	11.50	.25	2.88	1.15	11.83	.26	89.00	.32	.13	1.30	.03
4.4	Macrocystis pyrifera, No. 4, non-harvestable stems	....	2.84	1.50	.81	22.59	.19	1.54	.83	23.25	.20	90.15	.15	.08	2.29	.02
5.1	Macrocystis pyrifera, No. 5, harvestable leaves	....	1.96	1.48	.68	8.30	.18	1.51	.69	8.47	.18	85.39	.22	.10	1.24	.03
5.2	Macrocystis pyrifera, No. 5, harvestable stems	....	2.79	.79	.62	17.57	.14	.81	.64	18.07	.14	88.18	.10	.08	2.14	.02
5.3	Macrocystis pyrifera, No. 5, non-harvestable leaves	....	2.28	2.96	.81	8.69	.15	3.03	.83	8.89	.15	88.18	.36	.10	1.05	.02
5.4	Macrocystis pyrifera, No. 5, non-harvestable stems	....	3.04	1.40	.63	21.04	.17	1.44	.65	21.70	.17	89.76	.15	.07	2.22	.02
6.1	Macrocystis pyrifera, No. 6, harvestable leaves	....	1.78	1.02	.50	8.95	.15	1.04	.51	9.11	.15	83.67	.17	.08	1.49	.03
6.2	Macrocystis pyrifera, No. 6, harvestable stems	....	3.14	.57	.41	17.17	.14	.59	.42	17.73	.14	87.33	.07	.05	2.25	.02
6.3	Macrocystis pyrifera, No. 6, non-harvestable leaves	....	1.51	1.11	.54	8.23	.30	1.13	.55	8.36	.31	83.00	.19	.09	1.42	.05
6.4	Macrocystis pyrifera, No. 6, non-harvestable stems	....	2.75	.60	.45	17.93	.22	.62	.46	18.44	.23	88.21	.07	.05	2.17	.03
7.1	Macrocystis pyrifera, No. 7, harvestable leaves	....	1.33	.81	.61	6.47	.25	.82	.62	6.56	.25	83.23	.14	.10	1.10	.04
7.2	Macrocystis pyrifera, No. 7, harvestable stems	....	2.47	.48	.51	15.56	.11	.49	.52	15.95	.11	87.45	.06	.07	2.00	.01
8.1	Macrocystis pyrifera, No. 8, harvestable leaves	....	1.42	.84	.78	7.35	.23	.85	.79	7.46	.23	84.33	.13	.12	1.17	.04
8.2	Macrocystis pyrifera, No. 8, harvestable stems	....	2.91	.55	.59	18.76	.14	.57	.61	19.53	.14	88.87	.06	.07	2.15	.02
9.1	Macrocystis pyrifera, No. 9, harvestable leaves	....	2.45	1.01	.54	10.05	.21	1.01	.55	10.30	.21	81.78	.16	.08	1.57	.03

TABLE 2—(*Continued*)

Laboratory number	General description of Sample	Per cent of Water in air-dried Kelp	Composition of oven-dried samples (All data averages of two closely agreeing determinations): Per cent of Moisture	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Composition of water-free samples (Computed): Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Composition of fresh material (Computed): Per cent of Moisture	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine
9.2	Macrocystis pyrifera, No. 9, harvestable stems	22.19	4.55	.54	.41	18.03	.08	.57	.43	18.89	.08	87.90	.07	.05	2.29	.01
9.3	Macrocystis pyrifera, No. 9, non-harvestable leaves	10.73	2.68	1.61	.88	12.24	.09	1.65	.90	12.58	.09	86.90	.22	.12	1.65	.01
9.4	Macrocystis pyrifera, No. 9, non-harvestable stems	17.77	4.39	.88	.48	17.66	.15	.92	.50	18.47	.16	87.85	.11	.06	2.24	.02
10.1	Macrocystis pyrifera, No. 10, harvestable leaves	....	1.57	1.04	.62	10.52	.16	1.06	.63	10.69	.16	85.90	.15	.09	1.51	.02
10.2	Macrocystis pyrifera, No. 10, harvestable stems	27.85	3.76	.47	.48	18.75	.10	.49	.50	19.48	.10	88.28	.06	.06	2.28	.01
11.1	Macrocystis pyrifera, No. 11, harvestable leaves	9.25	1.81	1.13	.77	10.50	.29	1.15	.78	10.69	.30	83.58	.19	.13	1.76	.05
11.2	Macrocystis pyrifera, No. 11, harvestable stems	14.68	3.15	.74	.65	19.55	.14	.76	.67	20.19	.14	88.53	.09	.08	2.32	.02
12.1	Macrocystis pyrifera, No. 12, harvestable leaves	11.15	2.21	1.17	.66	11.78	.19	1.20	.67	12.05	.19	86.26	.16	.09	1.66	.03
12.2	Macrocystis pyrifera, No. 12, harvestable stems	15.95	3.86	.65	.42	20.02	.08	.68	.44	20.82	.08	88.59	.08	.05	2.38	.01
13.1	Macrocystis pyrifera, No. 13, harvestable leaves	....	1.78	1.55	1.08	15.26	.28	1.58	1.10	15.54	.29	87.09	.20	.14	2.00	.04
13.2	Macrocystis pyrifera, No. 13, harvestable stems	20.50	3.16	.70	.52	21.66	.08	.72	.54	22.37	.08	88.85	.08	.06	2.49	.01
14.1	Pelagophycus porra, No. 1, leaves	....	1.02	1.41	.81	17.80	.35	1.42	.82	17.98	.35	89.33	.15	.09	1.92	.04
14.2	Pelagophycus porra, No. 1, harvestable stem	26.47	2.92	.88	.48	29.67	.15	.91	.49	30.56	.16	92.09	.07	.04	2.42	.01
15.1	Pelagophycus porra, No. 4, leaves	18.56	1.84	1.24	.70	16.32	.37	1.26	.71	16.63	.38	86.84	.17	.09	2.19	.05
15.2	Pelagophycus porra, No. 4, harvestable stem	24.88	3.71	.98	.41	29.23	.16	1.02	.43	30.36	.16	91.53	.09	.04	2.57	.01

TABLE 2—(*Continued*)

Laboratory number	General description of Sample	Per cent of Water in air-dried Kelp	Composition of oven-dried samples (All data averages of two closely agreeing determinations)					Composition of water-free samples (Computed)				Composition of fresh material (Computed)				
			Per cent of Moisture	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Per cent of Moisture	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine
16.1	Pelagophycus porra, No. 5, leaves	18.65	1.93	1.40	.68	17.65	.32	1.43	.69	18.00	.33	86.70	.19	.09	2.39	.04
16.2	Pelagophycus porra, No. 5, harvestable stem	14.05	3.69	.96	.40	28.96	.18	1.00	.42	30.07	.18	91.44	.09	.04	2.57	.02
17.1	Pelagophycus porra, No. 6, leaves	9.93	2.62	1.78	.95	19.66	.24	1.83	.98	20.19	.24	90.70	.17	.09	1.88	.02
17.2	Pelagophycus porra, No. 6, harvestable stem	20.39	4.59	1.00	.92	26.59	.05	1.05	.96	27.87	.05	90.73	.10	.09	2.58	.01
18.1	Pelagophycus porra, No. 7, leaves	14.22	2.04	1.78	.93	20.05	.29	1.82	.95	20.47	.30	90.80	.17	.09	1.88	.03
18.2	Pelagophycus porra, No. 7, harvestable stem	18.05	4.10	1.00	.49	27.53	.11	1.04	.51	28.71	.12	91.04	.09	.05	2.57	.01
19	Egregia Laevigata, No. 1, complete strands	11.52	3.14	1.57	1.12	6.88	.03	1.62	1.16	7.10	.03	81.18	.30	.22	1.34	.01
20	Egregia Laevigata, No. 2, complete strands	10.71	2.11	2.15	1.06	10.91	.03	2.20	1.08	11.15	.03	86.16	.30	.15	1.54	.004
20.1	Macrocystis pyrifera, No. 22, harvestable leaves	....	3.32	2.75	.87	11.52	.12	2.82	.89	11.79	.12	88.15	.33	.11	1.40	.014
20.2	Macrocystis pyrifera, No. 22, harvestable stems	....	2.70	1.07	.45	24.40	.10	1.10	.46	25.08	.10	90.14	.11	.05	2.47	.010
21.1	Nereocystis Luetkeana, No. 17, leaves	....	1.80	1.79	.93	19.66	.15	1.82	.95	20.02	.15	91.75	.15	.08	1.65	.012
21.2	Nereocystis Luetkeana, No. 17, stem	....	1.46	1.00	.47	29.92	.04	1.02	.48	30.36	.04	93.20	.07	.03	2.06	.003
22.1	Macrocystis pyrifera, No. 14, harvestable leaves	....	1.44	3.05	1.22	12.92	.12	3.10	1.24	13.11	.12	87.30	.39	.16	1.67	.016
22.2	Macrocystis pyrifera, No. 14, harvestable stems	....	1.69	1.11	.66	19.93	.13	1.13	.67	20.27	.13	89.03	.12	.07	2.22	.015

TABLE 2—(*Continued*)

Laboratory number	General description of Sample	Per cent of Water in air-dried Kelp	Composition of oven-dried samples (All data averages of two closely agreeing determinations)					Composition of water-free samples (Computed)				Composition of fresh material (Computed)				
			Per cent of Moisture	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Per cent of Moisture	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine
23.1	Macrocystis pyrifera, No. 15, harvestable leaves	....	.92	2.56	1.26	11.79	.16	2.58	1.27	11.90	.16	86.20	.36	.18	1.64	.022
23.2	Macrocystis pyrifera, No. 15, harvestable stems	....	1.84	1.14	.78	19.29	.17	1.16	.79	19.65	.17	88.68	.13	.09	2.22	.02
24.1	Macrocystis pyrifera, No. 16, harvestable leaves	....	1.85	2.53	1.00	14.80	.12	2.58	1.02	15.08	.12	87.65	.32	.13	1.86	.015
24.2	Macrocystis pyrifera, No. 16, harvestable stems	....	2.25	1.04	.35	23.08	.09	1.06	.36	23.61	.09	89.58	.11	.04	2.46	.01
25.1	Macrocystis pyrifera, No. 17, harvestable leaves	....	1.08	3.04	1.01	9.87	.13	3.07	1.02	9.98	.13	85.55	.44	.15	1.44	.02
25.2	Macrocystis pyrifera, No. 17, harvestable stems	....	1.31	1.22	.54	19.37	.12	1.24	.55	19.63	.12	88.58	.14	.06	2.24	.014
25.3	Macrocystis pyrifera, No. 17, non-harvestable leaves	....	1.86	3.19	1.12	9.22	.08	3.25	1.14	9.39	.08	85.48	.47	.17	1.36	.012
25.4	Macrocystis pyrifera, No. 17, non-harvestable stems	....	2.25	1.20	.49	16.77	.11	1.23	.50	17.16	.11	87.53	.15	.06	2.14	.014
26.1	Macrocystis pyrifera, No. 18, harvestable leaves	....	.70	1.86	.76	13.33	.17	1.87	.77	13.42	.17	86.60	.25	.10	1.80	.023
26.2	Macrocystis pyrifera, No. 18, harvestable stems	....	.61	.98	.59	23.67	.16	.99	.59	23.82	.16	89.90	.10	.06	2.41	.02
26.3	Macrocystis pyrifera, No. 18, non-harvestable leaves	....	1.29	1.66	.56	14.86	.22	1.68	.57	15.05	.22	87.35	.21	.07	1.90	.03
26.4	Macrocystis pyrifera, No. 18, non-harvestable stems	....	1.43	.84	.46	23.48	.17	.85	.47	23.82	.17	89.75	.09	.05	2.44	.02
27.1	Nereocystis Luetkeana, No. 1, leaves	....	.74	1.85	.86	20.70	.05	1.86	.87	20.85	.05	91.55	.16	.07	1.76	.004
27.2	Nereocystis Luetkeana, No. 1, stem	....	.67	.88	.39	29.46	.04	.89	.39	29.66	.04	92.63	.07	.03	2.19	.003
28.1	Nereocystis Luetkeana, No. 2, leaves	....	1.16	1.90	.45	17.32	.08	1.92	.46	17.52	.08	90.55	.18	.04	1.66	.008

TABLE 2—(*Continued*)

Laboratory number	General description of Sample	of Water Per cent in air-dried Kelp	Composition of oven-dried samples (All data averages of two closely agreeing determinations)					Composition of water-free samples (Computed)				Composition of fresh material (Computed)				
			Per cent of Moisture	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Per cent of Moisture	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine
28.2	Nereocystis Luetkeana, No. 2, stem	....	1.42	1.86	.37	25.12	.05	1.89	.38	25.48	.05	91.68	.16	.03	2.12	.004
29.1	Nereocystis Luetkeana, No. 3, leaves	....	1.65	2.20	.90	17.34	.17	2.24	.92	17.63	.17	91.35	.19	.08	1.52	.015
29.2	Nereocystis Luetkeana, No. 3, stem	....	1.95	1.05	.38	28.02	.05	1.07	.39	28.58	.05	92.10	.08	.03	2.26	.004
30.1	Nereocystis Luetkeana, No. 4, leaves	....	1.86	1.97	1.11	19.36	.09	2.01	1.13	19.73	.09	91.70	.17	.09	1.64	.008
30.2	Nereocystis Luetkeana, No. 4, stem	....	1.57	.85	.51	30.00	.03	.86	.52	30.48	.03	93.28	.06	.03	2.05	.002
31.1	Nereocystis Luetkeana, No. 5, leaves	....	1.16	1.97	.98	19.92	.07	1.99	.99	20.15	.07	91.88	.16	.08	1.64	.006
31.2	Nereocystis Luetkeana, No. 5, stem	....	.90	1.11	.58	24.52	.06	1.12	.59	24.74	.06	91.75	.09	.05	2.04	.005
32.1	Nereocystis Luetkeana, No. 6, leaves	....	1.46	2.05	.94	19.40	.08	2.08	.95	19.69	.08	92.00	.17	.08	1.58	.007
32.2	Nereocystis Luetkeana, No. 6, stem	....	1.38	.99	.61	27.76	.06	1.00	.62	28.15	.06	92.80	.07	.04	2.03	.004
33.1	Nereocystis Luetkeana, No. 7, leaves	....	.92	2.06	.73	18.84	.08	2.08	.74	19.02	.08	91.53	.18	.06	1.61	.007
33.2	Nereocystis Luetkeana, No. 7, stem	....	1.51	1.33	.60	22.64	.10	1.35	.61	22.99	.10	91.20	.12	.05	2.02	.009
34.1	Nereocystis Luetkeana, No. 8, leaves	....	1.58	1.75	.78	20.50	.13	1.78	.79	20.83	.13	91.28	.16	.07	1.82	.012
34.2	Nereocystis Luetkeana, No. 8, stem	....	2.06	1.04	.55	26.00	.10	1.06	.56	26.55	.10	92.43	.08	.04	2.01	.008
35.1	Nereocystis Luetkeana, No. 9, leaves	....	.74	2.26	.82	17.44	.14	2.28	.83	17.57	.14	91.65	.19	.07	1.47	.012
35.2	Nereocystis Luetkeana, No. 9, stem	....	.95	1.32	.47	24.56	.08	1.33	.47	24.80	.08	91.15	.12	.04	2.20	.007

TABLE 2—(*Concluded*)

Laboratory number	General description of Sample	Per cent of Water in air-dried Kelp	Composition of oven-dried samples (All data averages of two closely agreeing determinations)					Composition of water-free samples (Computed)				Composition of fresh material (Computed)				
			Per cent of Moisture	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Per cent of Moisture	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine
36.1	Nereocystis Luetkeana, No. 10, leaves	....	1.72	2.26	.83	14.78	.09	2.30	.84	15.04	.09	90.18	.23	.08	1.48	.009
36.2	Nereocystis Luetkeana, No. 10, stem	....	2.06	1.39	.53	24.72	.06	1.42	.54	25.24	.06	91.68	.12	.05	2.10	.005
37.1	Nereocystis Luetkeana, No. 11, leaves	....	1.60	2.26	.76	16.28	.07	2.30	.77	16.54	.07	90.80	.21	.07	1.52	.007
37.2	Nereocystis Luetkeana, No. 11, stem	....	2.26	1.30	.59	26.84	.07	1.33	.60	27.46	.07	92.40	.10	.05	2.09	.005
38.1	Nereocystis Luetkeana, No. 12, leaves	....	1.75	2.02	.86	18.68	.15	2.06	.88	19.01	.15	91.15	.18	.08	1.68	.014
38.2	Nereocystis Luetkeana, No. 12, stem	....	2.81	1.13	.57	25.08	.06	1.16	.59	25.81	.06	91.90	.09	.05	2.09	.005
39.1	Nereocystis Luetkeana, No. 13, leaves	....	1.36	1.99	.83	18.66	.08	2.02	.84	18.92	.08	92.25	.16	.07	1.47	.006
39.2	Nereocystis Luetkeana, No. 13, stem	....	1.15	1.46	.47	22.64	.15	1.48	.48	22.90	.15	90.73	.14	.04	2.12	.014
40	Egregia Menziesii, No. 1, complete strands	....	2.73	2.76	1.27	9.48	.03	2.84	1.31	9.75	.03	83.25	.48	.22	1.63	.005
41	Egregia Menziesii, No. 2, complete strands	....	1.96	2.58	1.04	9.60	.03	2.63	1.06	9.79	.03	83.88	.42	.17	1.58	.005
42	Egregia Menziesii, No. 3, complete strands	....	1.58	2.75	1.36	9.42	.03	2.79	1.38	9.57	.03	83.73	.45	.22	1.56	.005
43	Laminaria Andersonii, entire plants	....	1.20	2.37	.75	5.80	.48	2.40	.76	5.87	.49	78.50	.52	.16	1.26	.105
44	Iridaea, entire plants	....	1.67	2.67	.67	2.22	.009	2.72	.68	2.26	.01	80.06	.54	.14	.45	.002

* The decimal system has been used throughout all tables for convenience in identifying samples, thus: .1 always indicates harvestable leaves; .2 always indicates harvestable stems; .3 always indicates non-harvestable leaves; .4 always indicates non-harvestable stems.

here. It seems to the writer, however, that there is sufficient uniformity in most of the determinations to justify a fairly definite opinion as to the value of kelps from the data here presented, for while there is occasionally an aberrant figure the variation of most of the determinations from the average is not large. A remarkable uniformity of the moisture content of analagous portions of plants is particularly noticeable.

The summary on page 199 indicates the distribution of important constituents.

The nitrogen, phosphoric acid and iodine content of the leaves is uniformly higher than that of the stems of the same species. The potash content of the stems is very much greater than that of the leaves, being nearly two to one in *Macrocystis*. The moisture content of the stems is invariably slightly greater than that of the leaves.

The striking differences in composition between the leaves and stems of kelps might perhaps suggest the possibility of a segregation of leaves and stems in commercial production. To any one who handles these plants, however, it becomes evident that such segregation is out of the question, and it would seem therefore that estimates as to the value of the plants must be based upon the composition of the harvestable leaves and stems taken together rather than individually. The data included in Table 4 are presented with this in mind.

The figures for the non-harvestable portion are included merely because of their general interest, and it is not contended that they are of any particular value for our present purpose. Some inconsistency will perhaps be noticed, however, in that the figures for individual constituents in the harvestable portion are sometimes higher and sometimes lower than the corresponding figures for the non-harvestable portion. This is not a real inconsistency, but is due to differences in the relative amounts of leaf to stem, both in harvestable and non-harvestable parts.

The summary of the average composition of the harvestable portions presented in the table on page 204 is of particular interest.

Of the giant kelps, *Macrocystis* is the only one growing on both the southern and central Californian coast. The analyses indicate that the specimens from the north are distinctly superior in nitrogen, phosphoric acid and potash, but slightly inferior in iodine content. Comparing all plants on the water-free basis, it is evident that *Pelagophycus* is the most valuable species, in as much as it contains the most potash and iodine and comparable quantities of nitrogen and phosphoric acid. *Nereocystis* is next because of high potash, even though distinctly inferior in iodine content. At this point, however,

TABLE 3

Average Composition of Harvestable Leaves and Stems of Kelp

No. of samples represented	Description of samples	Composition calculated to Water-free Basis: Percentage of Nitrogen	Percentage of Phosphoric Acid (P_2O_5)	Percentage of Potash (K_2O)	Percentage of Iodine	Composition calculated to Fresh Material: Percentage of Moisture	Percentage of Nitrogen	Percentage of Phosphoric Acid (P_2O_5)	Percentage of Potash (K_2O)	Percentage of Iodine
13	Macrocystis leaves, San Diego and La Jolla	1.26	.73	10.71	.22	84.66	.19	.11	1.58	.03
6	Macrocystis leaves, Pacific Grove and vicinity	2.67	1.03	12.55	.14	86.91	.35	.14	1.64	.018
19	Macrocystis leaves, San Diego, La Jolla and Pacific Grove	1.71	.83	11.29	.20	85.65	.24	.12	1.60	.03
13	Macrocystis stems, San Diego and La Jolla	.71	.55	19.49	.12	88.25	.08	.07	2.28	.014
6	Macrocystis stems, Pacific Grove and vicinity	1.11	.57	22.01	.13	89.29	.12	.06	2.34	.014
19	Macrocystis stems, San Diego, La Jolla and Pacific Grove	.84	.56	20.28	.12	88.59	.09	.06	2.30	.014
13	Nereocystis leaves, Pacific Grove and vicinity	2.07	.85	18.65	.10	91.37	.18	.07	1.60	.009
13	Nereocystis stems, Pacific Grove and vicinity	1.23	.52	26.37	.07	91.98	.10	.04	2.10	.006
5	Pelagophycus leaves, San Diego and vicinity	1.55	.83	18.65	.32	88.87	.17	.09	2.05	.04
5	Pelagophycus stems, San Diego and vicinity	1.00	.56	29.52	.13	91.38	.09	.05	2.54	.01

TABLE 4

COMPOSITION OF ENTIRE HARVESTABLE AND NON-HARVESTABLE PORTIONS

Laboratory number	General description of Sample	Composition of Entire Harvestable and Non-harvestable Portions (Calculated to water-free basis)				Composition of Entire Harvestable and Non-harvestable Portions (Calculated to fresh material)					Composition of Entire Harvestable and Non-harvestable Portions (Calculated to air-dry basis of 16 per cent Moisture)			
		Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Per cent of Moisture	Per cent of Nitrogen	Per cent P_2O_5	Per cent K_2O	Per cent of Iodine	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine
1.1 and 1.2	Macrocystis pyrifera, No. 1, entire harvestable portion	1.57	.90	12.31	.22	85.27	.23	.13	1.81	.03	1.32	.76	10.34	.18
1.3 and 1.4	Macrocystis pyrifera, No. 1, entire non-harvestable portion	1.83	.91	12.41	.28	85.75	.26	.13	1.77	.04	1.54	.79	10.42	.24
2.1 and 2.2	Macrocystis pyrifera, No. 2, entire harvestable portion	1.14	.65	15.19	.25	86.80	.15	.09	2.01	.03	.96	.55	12.76	.21
2.3 and 2.4	Macrocystis pyrifera, No. 2, entire non-harvestable portion	2.06	1.38	13.04	.41	87.12	.27	.18	1.68	.05	1.73	1.16	10.95	.34
3.1 and 3.2	Macrocystis pyrifera, No. 3, entire harvestable portion	.81	.53	15.58	.17	85.35	.12	.08	2.28	.03	.68	.45	13.09	.14
3.3 and 3.4	Macrocystis pyrifera, No. 3, entire non-harvestable portion	.79	.45	16.63	.22	87.05	.10	.06	2.15	.03	.66	.38	13.97	.18
4.1 and 4.2	Macrocystis pyrifera, No. 4, entire harvestable portion	1.91	.87	14.30	.18	88.17	.23	.10	1.69	.02	1.60	.73	12.01	.15
4.3 and 4.4	Macrocystis pyrifera, No. 4, entire non-harvestable portion	2.27	1.00	16.99	.23	89.55	.24	.11	1.78	.02	1.91	.84	14.27	.19
5.1 and 5.2	Macrocystis pyrifera, No. 5, entire harvestable portion	1.29	.67	11.44	.17	86.38	.18	.09	1.56	.02	1.08	.56	9.61	.14
5.3 and 5. 4	Macrocystis pyrifera, No. 5, entire non-harvestable portion	2.39	.76	14.06	.16	88.87	.27	.08	1.57	.02	2.01	.64	11.81	.13
6.1 and 6.2	Macrocystis pyrifera, No. 6, entire harvestable portion	.94	.49	11.10	.15	84.69	.14	.07	1.70	.02	.79	.41	9.32	.13
6.3 and 6.4	Macrocystis pyrifera, No. 6, entire non-harvestable portion	.99	.53	11.06	.28	84.80	.15	.08	1.68	.04	.83	.45	9.29	.24
7.1 and 7.2	Macrocystis pyrifera, No. 7, entire harvestable portion	.73	.59	9.02	.21	84.59	.11	.09	1.39	.03	.61	.50	7.58	.18

TABLE 4—(*Continued*)

Laboratory number	General description of Sample	Composition of Entire Harvestable and Non-harvestable Portions (Calculated to water-free basis): Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Composition of Entire Harvestable and Non-harvestable Portions (Calculated to fresh material): Per cent of Moisture	Per cent of Nitrogen	Per cent P_2O_5	Per cent K_2O	Per cent of Iodine	Composition of Entire Harvestable and Non-harvestable Portions (Calculated to air-dry basis of 16 per cent Moisture): Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine
8.1 and 8.2	Macrocystis pyrifera, No. 8, entire harvestable portion	.80	.76	9.74	.22	85.47	.12	.11	1.42	.03	.67	.64	8.18	.18
9.1 and 9.2	Macrocystis pyrifera, No. 9, entire harvestable portion	.87	.51	13.31	.17	86.04	.12	.07	1.86	.02	.73	.43	11.18	.14
9.3 and 9.4	Macrocystis pyrifera, No. 9, entire non-harvestable portion	1.11	.61	16.90	.14	87.61	.14	.08	2.09	.02	.93	.51	14.19	.12
10.1 and 10.2	Macrocystis pyrifera, No. 10, entire harvestable portion	.91	.60	13.02	.14	86.62	.12	.08	1.74	.02	.76	.50	10.94	.12
11.1 and 11.2	Macrocystis pyrifera, No. 11, entire harvestable portion	1.07	.76	12.64	.26	84.92	.16	.11	1.91	.04	.90	.64	10.62	.22
12.1 and 12.2	Macrocystis pyrifera, No. 12, entire harvestable portion	1.06	.61	14.38	.17	86.97	.14	.08	1.87	.02	.89	.51	12.08	.14
13.1 and 13.2	Macrocystis pyrifera, No. 13, entire harvestable portion	1.30	.92	17.75	.22	87.71	.16	.11	2.18	.03	1.09	.77	14.91	.18
14.1 and 14.2	Pelagophycus porra, No. 1, entire harvestable portion	1.24	.70	22.48	.28	90.51	.12	.07	2.13	.03	1.04	.59	18.88	.24
15.1 and 15.2	Pelagophycus porra, No. 4, entire harvestable portion	1.18	.62	20.99	.31	88.81	.13	.07	2.35	.03	.99	.52	17.63	.26
16.1 and 16.2	Pelagophycus porra, No. 5, entire harvestable portion	1.29	.60	21.81	.28	88.68	.15	.07	2.47	.03	1.08	.50	18.32	.24
17.1 and 17.2	Pelagophycus porra, No. 6, entire harvestable portion	1.57	.97	22.70	.18	90.71	.15	.09	2.11	.02	1.32	.81	19.07	.15
18.1 and 18.2	Pelagophycus porra, No. 7, entire harvestable portion	1.61	.83	22.65	.25	90.86	.15	.08	2.07	.02	1.35	.70	19.02	.21
19	Egregia Laevigata, No. 1, complete strands	1.62	1.16	7.10	.03	81.18	.30	.22	1.34	.01	1.36	.97	5.96	.02
20	Egregia Laevigata, No. 2, complete strands	2.20	1.08	11.15	.03	86.16	.30	.15	1.54	.004	1.85	.91	9.37	.02

TABLE 4—(*Continued*)

		Composition of Entire Harvestable and Non-harvestable Portions (Calculated to water-free basis)				Composition of Entire Harvestable and Non-harvestable Portions (Calculated to fresh material)					Composition of Entire Harvestable and Non-harvestable Portions (Calculated to air-dry basis of 16 per cent Moisture)			
Laboratory number	General description of Sample	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Per cent of Moisture	Per cent of Nitrogen	Per cent P_2O_5	Per cent K_2O	Per cent of Iodine	Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine
22.1 and 22.2	Macrocystis pyrifera, No. 14, entire harvestable portion	2.71	1.13	14.51	.12	87.68	.33	.14	1.79	.02	2.28	.95	12.19	.10
23.1 and 23.2	Macrocystis pyrifera, No. 15, entire harvestable portion	2.25	1.16	13.70	.16	86.87	.30	.15	1.80	.02	1.89	.97	11.51	.13
24.1 and 24.2	Macrocystis pyrifera, No. 16, entire harvestable portion	1.89	.72	18.96	.11	88.61	.22	.08	2.16	.01	1.59	.61	15.93	.09
25.1 and 25.2	Macrocystis pyrifera, No. 17, entire harvestable portion	2.45	.86	13.25	.13	86.74	.32	.11	1.76	.02	2.06	.72	11.13	.11
25.3 and 25.4	Macrocystis pyrifera, No. 17, entire non-harvestable portion	2.18	.80	13.51	.10	86.64	.29	.11	1.80	.01	1.83	.67	11.36	.08
26.1 and 26.2	Macrocystis pyrifera, No. 18, entire harvestable portion	1.73	.74	15.13	.17	87.28	.22	.09	1.92	.02	1.45	.62	12.71	.14
26.3 and 26.4	Macrocystis pyrifera, No. 18, entire non-harvestable portion	1.37	.53	18.36	.20	88.38	.16	.06	2.13	.02	1.15	.45	15.42	.17
27.1 and 27.2	Nereocystis Luetkeana, No. 1, entire plant	1.48	.68	24.30	.05	92.01	.12	.05	1.94	.004	1.24	.57	20.41	.04
28.1 and 28.2	Nereocystis Luetkeana, No. 2, entire plant	1.91	.43	19.71	.07	90.89	.17	.04	1.80	.007	1.60	.36	16.55	.06
29.1 and 29.2	Nereocystis Luetkeana, No. 3, entire plant	1.93	.78	20.45	.14	91.55	.16	.07	1.73	.01	1.62	.66	17.17	.12
30.1 and 30.2	Nereocystis Luetkeana, No. 4, entire plant	1.50	.86	24.54	.06	92.49	.11	.06	1.84	.005	1.26	.72	20.61	.05
31.1 and 31.2	Nereocystis Luetkeana, No. 5, entire plant	1.45	.74	23.01	.06	91.80	.12	.06	1.89	.005	1.22	.62	19.33	.05
32.1 and 32.2	Nereocystis Luetkeana, No. 6, entire plant	1.81	.87	21.80	.08	92.21	.14	.07	1.70	.006	1.52	.73	18.31	.07
33.1 and 33.2	Nereocystis Luetkeana, No. 7, entire plant	1.88	.70	20.03	.09	91.42	.16	.06	1.72	.007	1.58	.59	16.82	.07

TABLE 4—(*Concluded*)

Laboratory number	General description of Sample	Composition of Entire Harvestable and Non-harvestable Portions (Calculated to water-free basis): Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine	Composition of Entire Harvestable and Non-harvestable Portions (Calculated to fresh material): Per cent of Moisture	Per cent of Nitrogen	Per cent P_2O_5	Per cent K_2O	Per cent of Iodine	Composition of Entire Harvestable and Non-harvestable Portions (Calculated to air-dry basis of 16 per cent Moisture): Per cent of Nitrogen	Per cent of P_2O_5	Per cent of K_2O	Per cent of Iodine
34.1 and 34.2	Nereocystis Luetkeana, No. 8, entire plant	1.45	.69	23.38	.12	91.83	.12	.06	1.91	.01	1.22	.58	19.64	.10
35.1 and 35.2	Nereocystis Luetkeana, No. 9, entire plant	1.92	.69	20.33	.12	91.47	.16	.06	1.73	.01	1.61	.58	17.08	.10
36.1 and 36.2	Nereocystis Luetkeana, No. 10, entire plant	2.06	.76	17.78	.08	90.63	.19	.07	1.67	.008	1.73	.64	14.93	.07
37.1 and 37.2	Nereocystis Luetkeana, No. 11, entire plant	2.11	.74	18.71	.07	91.17	.19	.07	1.65	.006	1.77	.62	15.72	.06
38.1 and 38.2	Nereocystis Luetkeana, No. 12, entire plant	1.78	.79	21.07	.12	91.39	.15	.07	1.81	.01	1.50	.66	17.70	.10
39.1 and 39.2	Nereocystis Luetkeana, No. 13, entire plant	1.81	.70	20.43	.11	91.73	.15	.06	1.69	.009	1.52	.59	17.14	.09
40	Egregia Menziesii, No. 1, complete strands	2.84	1.31	9.75	.03	83.25	.48	.22	1.63	.005	2.39	1.10	8.19	.02
41	Egregia Menziesii, No. 2, complete strands	2.63	1.06	9.79	.03	83.88	.42	.17	1.58	.005	2.21	.89	8.22	.02
42	Egregia Menziesii, No. 3, complete strands	2.79	1.38	9.57	.03	83.73	.45	.22	1.56	.005	2.34	1.16	8.04	.02
43	Laminaria Andersonii, entire plants	2.40	.76	5.87	.48	78.50	.52	.16	1.26	.10	2.02	.64	4.93	.40
44	Iridaea, entire plants	2.72	.68	2.26	.01	80.06	.54	.14	.45	.002	2.28	.57	1.90	.007

TABLE 5

AVERAGE COMPOSITION OF ENTIRE HARVESTABLE PORTIONS

No. of samples represented	Description of Samples	Average Composition calculated to Water-free Basis				Average Composition calculated to Fresh Material				
		Percentage of Nitrogen	Percentage of Phosphoric Acid (P_2O_5)	Percentage of Potash (K_2O)	Percentage of Iodine	Percentage of Moisture	Percentage of Nitrogen	Percentage of Phosphoric Acid (P_2O_5)	Percentage of Potash (K_2O)	Percentage of Iodine
13	Macrocystis pyrifera, San Diego and La Jolla	1.11	.68	13.06	.19	86.08	.15	.09	1.80	.03
5	Macrocystis pyrifera, Pacific Grove and vicinity	2.21	.92	15.11	.14	87.44	.28	.11	1.88	.02
18	Macrocystis pyrifera, San Diego, La Jolla and Pacific Grove	1.41	.75	13.63	.18	86.41	.19	.10	1.82	.03
13	Nereocystis Luetkeana, Pacific Grove and vicinity	1.78	.73	21.20	.09	91.58	.15	.06	1.78	.008
5	Pelagophycus porra, San Diego and vicinity	1.37	.74	22.12	.26	89.92	.14	.07	2.23	.03
2	Egregia Laevigata, San Diego and vicinity, complete strands	1.91	1.12	9.12	.03	83.67	.30	.18	1.44	.01
3	Egregia Menziesii, Pacific Grove and vicinity, complete strands	2.75	1.25	9.70	.03	83.62	.45	.20	1.59	.005
1	Laminaria Andersonii, Pacific Grove and vicinity, entire plant	2.40	0.76	5.87	.48	78.50	.52	.16	1.26	.10
1	Iridaea Laminarioides, Pacific Grove and vicinity, entire plant	2.72	0.68	2.26	.01	80.06	.54	.14	0.45	.002

it should be accentuated that the cost of harvesting and drying fresh kelp are important economic factors in the production of dried kelp, so that estimates of the relative value of these materials should be based on the fresh material rather than the dried. On this basis, *Pelagophycus* continues to hold first place, but *Nereocystis* drops below *Macrocystis,* being distinctly inferior to the latter in every respect. To obtain one ton of water-free *Nereocystis* would require the harvesting and drying of 11.9 tons of the fresh plants as against 7.4 tons of *Macrocystis.* The superiority of dried *Nereocystis* over dried *Macrocystis* is not sufficient to overcome the handicap of the large amount of water in the fresh material. In view of the comparative sparseness of *Pelagophycus* and the inferiority of *Nereocystis* it would seem that *Macrocystis* would be the most important source of raw material if it is found practicable to utilize kelps for manufacturing purposes.

RECOVERY OF POTASH AND IODINE

Leaving out of consideration, for the present, the possibility of obtaining economically valuable substances from the organic (non-salt) portions of kelp, it is evident that the separation of potash and iodine are of the first importance. It has been shown elsewhere[8] that when kelps are dried slowly there is always a tendency to form a crust or coating (efflorescence) on the surface of the plant. In some cases this apparently amounts to a considerable proportion of the salts present. The table on page 206 indicates what is to be expected in this respect.

In the case of *Macrocystis* leaves only a slight efflorescence occurred and the salts formed a thin, closely adherent layer, preventing separation. The percentages of salts effloresced by the *Macrocystis* stems, *Nereocystis* leaves and *Nereocystis* stems were respectively 15, 24 and 43. These contained no iodine, but carried extraordinary percentages of potash. If it is borne in mind that muriate of potash contains 63.1 per cent of potash (K_2O), it appears that the potash in the effloresced salts (60.85 to 61.92 per cent) represents muriate of a high degree of purity (over 95 per cent). In spite of this, the fact that the potash effloresced never exceeds 58.7 per cent of the total present in any sample (see *Nereocystis* stems) indicates that further extraction of the residual kelp presumably by water would be necessary, if the remaining potash salts are to be separated and iodine recovered. If

[8] On the Chemistry of Certain Algae of the Pacific Coast, by David M. Balch, Journal of Industrial and Engineering Chemistry, Vol. 1, No. 12, December, 1909.

TABLE 6

EFFLORESCENCE OF SALTS FROM 1000 GRAMS OF FRESH KELP

Number	Description of Samples	Total Salts in Kelp	Total Potash in Kelp	Crude Salts effloresced	Per cent Potash in effloresced salts	Potash effloresced	Per cent of totals effloresced		
							Salts	Potash	Iodine
20.1	Macrocystis leaves	49.2 g.	13.9 g.	0.0 g.	0.0	0.0 g.	0.0	0.0	0.0
20.2	Macrocystis stems	52.0 g.	24.9 g.	7.9 g.	61.27	4.8 g.	15.0	19.3	0.0
21.1	Nereocystis leaves	40.8 g.	15.7 g.	9.97 g.	60.85	6.1 g.	24.4	38.9	0.0
21.2	Nereocystis stems	45.7 g.	20.8 g.	19.75 g.	61.92	12.2 g.	43.2	58.7	0.0

the highly absorbent tissues of the plants have to be again saturated with water it would appear that the preliminary drying, incident to causing efflorescence to occur, would be an unnecessary step. Such a step would only be justified in case the subsequent treatment of the residual kelp is by a dry process, and any dry process would involve either the loss of organic matter, as in burning to obtain kelp ash, or loss of iodine if the residue is merely dried, ground and used as a low grade potash fertilizer.

In attempts to separate a complex mixture of colloidal and crystallizable material such as the tissues of kelp the method of water extraction is the first to suggest itself. The possibilities of this method are indicated by a study of the table on page 208.

Potash.—A large proportion of the potash (70.1–84.8 per cent) was extracted in every case from the fresh kelp, and still more (90.6-95.4 per cent) from the dried and ground material.

Iodine.—In all cases but one most of the iodine was extractable from fresh kelp and the yield from the dried and ground kelp was materially greater in five out of the six samples.

Organic Matter.—Considerable quantities of organic matter appear in the extract from fresh kelp and these are greatly increased when the dried and ground kelp is used.

There is evidently no difficulty in dissolving in water the potash and iodine constituent in kelp. When the kelp has been previously dried and ground the extraction is, as might be expected, much more efficient. Doubtless if the method of multiple extraction were used practically all of the potash and iodine would be removed from the tissues. Unfortunately large percentages of organic matter also dissolve whenever extraction of salts is at all efficient. These discolor the solutions and seriously interfere with the subsequent crystallization of the potash salts. Salts obtained from such solutions are always dark in color and difficult to separate. To secure clean, white potash salts either by fractional crystallization or by complete evaporation of the solutions is impossible without burning off the organic matter present. The salts remaining after incineration have a fairly high purity, corresponding to 60–80 per cent muriate of potash. For *Macrocystis* they would contain about 41 per cent of potash equivalent to muriate of 64 per cent purity. The procedure involves a loss of one-sixth to one-third of the organic matter of kelp and leaves the remaining organic matter (practically free from potash and iodine) saturated with water. This residuum represents approximately one hundred pounds of organic matter and three pounds of nitrogen for every ton of fresh kelp. Its utilization will necessarily depend upon

TABLE 7

SHOWING WATER EXTRACTIONS[9] OF FRESH AND DRIED KELP:

Calculated as grams of substance in 1 kilo of fresh kelp

Sample numbers	Total dry matter Per cent	Totals						Water soluble Two extractions Fresh Kelp						Water soluble Two extractions, Dried and Ground					
		Org.	Total salts	K_2O	N	P_2O_5	I	Org.	Total salts	K_2O	N	P_2O_5	I	Org.	Total salts	K_2O	N	P_2O_5	I
45.1[1]	8.1	39.3	43.7	16.2	1.54	.66	.099	11.3	35.3	13.3	.51	.24	.083	15.7	40.9	15.2	.42	.49	.093
45.2[2]	7.7	30.4	47.6	23.0	.84	.41	.055	4.8	38.8	19.1	.22	.15	.038	10.3	44.4	21.9	.22	.34	.037
46.1[3]	12.1	66.3	55.8	20.4	2.34	.77	.12	7.9	36.4	14.5	.45	.27	.086	14.1	47.4	18.5	.58	.60	.092
46.2[4]	10.5	54.8	52.2	24.4	1.07	.59	.139	10.2	35.6	17.1	.29	.19	.091	27.2	48.9	23.0	.33	.46	.124
47.1[5]	11.7	69.7	49.3	17.7	1.63	1.14	.369	19.7	37.7	15.0	.30	.33	.308	27.8	41.2	16.3	.30	.88	.333
47.2[6]	8.2	31.0	51.9	25.9	.71	.37	1.83	6.3	38.9	19.4	.17	.15	.067	11.9	48.0	24.7	.17	.37	.156

PERCENTAGE EXTRACTION OF KELPS

Sample numbers	Description	From Fresh Material						From Dried and Ground Material					
		Org.	Total salts	K_2O	N	P_2O_5	I	Org.	Total salts	K_2O	N	P_2O_5	I
45.1	Nereocystis leaves	28.8	80.8	82.1	33.2	36.5	83.8	40.0	93.6	93.8	27.3	74.4	93.9
45.2	Nereocystis stems	15.7	81.5	83.0	26.8	37.3	69.1	33.8	93.3	95.4	26.0	82.2	67.3
46.1	Macrocystis leaves	11.9	65.2	71.1	19.3	34.8	71.7	21.3	85.0	90.6	24.7	77.3	76.7
46.2	Macrocystis stems	18.6	68.2	70.1	27.2	31.5	65.5	49.4	93.6	94.3	31.2	78.3	89.2
47.1	Pelagophycus leaves	28.3	76.5	84.8	18.2	29.1	83.5	39.9	83.6	92.1	18.1	76.8	90.4
47.2	Pelagophycus stems	20.5	75.0	74.9	23.8	41.6	36.6	38.4	92.5	95.4	23.4	98.6	85.3

[1] Nereocystis leaves.
[2] Nereocystis stems.
[3] Macrocystis leaves.
[4] Macrocystis stems.
[5] Pelagophycus leaves.
[6] Pelagophycus stems.

[9] In these extractions one part of fresh kelp and the weight of dried and ground kelp equivalent to one part of fresh kelp were treated with approximately six parts of water and allowed to stand for forty-eight hours.

its humus-making power and nitrogen content, if used for fertilizing purposes, or upon its containing organic principles of commercial value. Other data reported elsewhere[10] indicate the presence of no such valuable principles. Such material would unquestionably have some value as a humus producer. Its value in this respect, together with its nitrogen value, might possibly justify the cost of drying and grinding. In the absence of definite market quotations for humus it hardly seems worth while to attempt to estimate the cost of production of such a commodity. The above procedure, however, or some modification thereof would seem to be the only one by which potash and iodine are recoverable from kelp without substantial loss of organic compounds which might serve as a source of humus. On the other hand, if it be assumed that the humus-making power of the organic constituents is not sufficiently great to justify the involved procedure described above, it at once becomes evident that the only logical method of manufacture would be the complete destruction of the organic matter by burning and the comparatively simple procedure involved in the extraction of potash and iodine from the char, followed by fractional crystallization. Hoagland has shown that in the residuum obtained from the destructive distillation of *Macrocystis*[11] three grades of potash salts of high purity may be obtained, the average composition of these amounting to 55 per cent potash, or muriate of 87 per cent purity. The salts remaining in the mother liquor containing approximately 19 per cent potash and 1½ per cent of iodine, practically all of which is recoverable.

Summary of Methods of Procedure.—(*a*) Partial drying, separation of effloresced salts (probably containing less than one-third of the total potash), drying and grinding the residuum for use as a low grade potash and nitrogen fertilizer. This method is of doubtful value for all varieties of plants, particularly for *Macrocystis*.

(*b*) Extraction of most of the potash and iodine from the fresh or dried material by lixiviation with water, evaporation of the solution to dryness followed by charring, separation of potash salts and iodine from the char, drying and grinding the residuum containing 80 per cent of the nitrogen and two-thirds or more of the organic matter, thus furnishing a humus-making material (organic matter) containing approximately 3 per cent of nitrogen. This method involves the least loss of valuable constituents, but requires the handling of bulky solu-

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[10] Study of the Organic Constituents of Pacific Coast Kelps, by D. R. Hoagland, unpublished manuscript.

[11] Unpublished manuscript, by D. R. Hoagland.

tions of viscous materials, evaporation of large quantities of water and extensive equipment.

(*c*) Charring of dried kelp, lixiviation of char, separation of most of the potash as high grade salts and of about 80 per cent of the iodine, drying of the charcoal obtained. This method involves loss of nitrogen and carbonaceous material, but is relatively simple and economical in practice.

Possibilities of Developing a Kelp Industry.—The development of such an industry will depend upon the relation of the cost of production and the prices obtainable for the products. It would be useless with data of the character obtainable in the laboratory to attempt to formulate the cost of the various procedures involved in the production of the commodities mentioned. Any such estimate would be a very rough approximation and definite figures could only be obtained as a result of actual factory experience. Furthermore, the cost of harvesting the plants is extremely problematical. In the absence of data covering these points estimates of costs are likely to be futile. Estimates of the value of the product, however, are useful as indicating the obvious limitations to which commercial production will be confined. The maximum value of the constituents obtainable from kelp are indicated in the following table:

Composition of Kelp (Macrocystis)

	Percentage	Pounds per ton	Maximum Recovery Per cent	Maximum Recovery Pounds	Price per pound	Total value
Moisture	86.41	1728.2	.....	....	....	.....
Nitrogen	.19	3.8	80	3.04	15c	$0.46
Potash	1.82	36.4	100	36.4	3¾c	$1.36
Iodine	.03	.6	80	.48	$3.00	$1.44

The commodities obtainable are iodine, high grade muriate of potash and fertilizer filler comprising the bulk of the organic matter of kelp freed from all soluble constituents (salts) and carrying 3 per cent of nitrogen.

It is not believed commercially possible to manufacture sulfate of ammonia from kelp, because it has been shown by Turrentine[12] that in the destructive distillation of kelps a large proportion of the nitrogen is evolved as such and not as ammonia. Again Hoagland has shown the same thing and, furthermore, gives data[13] indicating

[12] Note on the Distillation of Kelp, by J. W. Turrentine, Proceedings of the Eighth International Congress of Applied Chemistry, Vol. 15, p. 313.

[13] Unpublished manuscript, by D. R. Hoagland.

that there are no special by-products from the destructive distillation of such a character as to justify the expectation that a part of the cost of the necessary distillation could be defrayed by profits from such other products. The commercial value of the potash is unquestionably equal to that of the potash obtainable from high grade muriate of potash, and the market quotation for this commodity is used in the above estimate. The commercial value of the nitrogen is taken at approximately the cost of nitrogen in nitrate of soda. The third commodity, iodine, is taken to have a value equal to that of recent market quotations for this substance as obtained from other sources. It has been pointed out that it is hardly reasonable to expect that the iodine price will be maintained in the case of a large production from kelp, so that current market prices unquestionably represent the maximum value which could be expected from this source.

It will be seen from the figures given that the value of the various commodities, assuming the maximum recovery of each constituent is $3.26 per ton of wet kelp. If we assume that market conditions will not permit of the sale of iodine in competition with that obtained from other sources of supply, the maximum value of the remaining constituents is $1.82 per ton of wet kelp.

The data heretofore given indicate that the production of manufactured products from kelp is unquestionably a relatively complicated process. The estimates show that the gross income derivable from the various products is not great. It would seem, therefore, that expectations of enormous profits from the development of a kelp industry are not likely to be realized. On the other hand, the data do not exclude the possibility of some profit.

DRIED AND GROUND KELP AS A COMMERCIAL PRODUCT

The remaining procedure for the manufacture of kelp which would seem to offer commercial opportunity is the drying and grinding of kelp and selling it as such. The manipulation and equipment involved is of the simplest character and the method as a whole would seem to offer fair opportunities for success. The objections urged are that it involves the loss of iodine and the possibility that the product obtained will be of less commercial value per unit of potash and nitrogen than that of high grade manufactured products. Furthermore, that there is a prejudice against this material on account of the fact that it contains a certain proportion of sodium chloride. Finally, that manufactured products would yield a higher price and

lower freight rate per unit of potash than does dried kelp. Of all of the objections urged, the last, namely, that the cost of transportation of high grade manufactured products would be less than that of the comparatively low grade dried kelp would appear to be the only valid one. This latter objection will disappear if the cost of manufacturing the high grade product is sufficiently great to offset the benefit of a low freight rate. The difficulties of making exact estimates of the cost of manufacturing high grade products have been set forth. It would seem, however, that no such comparisons are necessary, provided the low grade material actually has sufficient value as compared with commodities of similar potash content carrying equal freight rates.

It is frequently stated that the value of dried and ground kelp will be materially diminished because of its content of sodium chloride, and attempts have been made to remove this salt from the kelp by washing with water. No such method is practicable because of the large quantities of potassium chloride relatively to sodium chloride in the principal varieties of kelp. The only possible method of separating the sodium salts from the potassium salts is that of fractional crystallization heretofore outlined. All attempts to wash sodium chloride out of either the fresh or dried and ground kelp will simply result in the removal of both potassium and sodium salts in amounts commensurate with their solubilities and relative quantities.

The following table of analyses by P. L. Hibbard of this laboratory indicates the composition of the various salts found in kelp.

TABLE 8

PERCENTAGE COMPOSITION OF THE ASH OF THE HARVESTABLE PORTIONS OF MACROCYSTIS PYRIFERA, NEREOCYSTIS LUETKEANA, AND PELAGOPHYCUS PORRA

	Macrocystis pyrifera	Nereocystis Luetkeana	Pelagophycus porra
Ca	4.96	2.10	2.09
Mg	2.24	1.55	1.71
Na	10.52	11.05	8.63
K	29.46	32.66	34.73
Fe_2O_3 / Al_2O_3	.43	.17	.26
Cl	34.93	40.89	40.83
SO_4	7.92	4.63	4.84
CO_3	4.44	3.10	1.66
PO_4	2.30	1.91	2.18
	97.20	98.06	96.93
Total ash in water-free material,	35.62	50.57	52.66

Percentage Composition of Commercial Salts Containing Chlorides

Principles and Practice of Agricultural Analysis, Vol. II, H. W. Wiley

	Muriate of Potash			Potash Manure Salts				
Basis	90–95	80–85	70–75	Minimum 20	Minimum 30	Kainit	Carnallit	Sylvinit
Actual potash (K_2O)	57.9	52.7	46.7	21.0	30.6	12.8	9.8	17.4
Minimum guarantee (K_2O)	56.8	50.5	44.1	20.0	30.0	12.4	9.0	12.4
Sulfate of potash	......	......	1.7	2.0	1.2	21.3	......	1.5
Muriate of potash	91.7	83.5	72.5	31.6	47.6	2.0	15.5	26.3
Sulfate of magnesia	0.2	0.4	0.8	10.6	9.4	14.5	12.1	2.4
Chlorid of magnesia	0.2	0.3	0.6	5.3	4.8	12.4	21.5	2.6
Chlorid of sodium	7.1	14.5	21.2	40.2	26.2	34.6	22.4	56.7
Sulfate of lime	......	......	0.2	2.1	2.2	1.7	1.9	2.8
Insoluble substances	0.2	0.2	0.5	4.0	3.5	0.8	0.5	3.2
Water	0.6	1.1	2.5	4.2	5.1	12.7	26.1	4.5
Potassium, sodium and chlorine—								
Potassium	48.09	43.79	38.78	17.46	25.49	10.59	8.13	14.46
Sodium	2.79	5.70	8.34	15.81	10.31	13.61	8.81	22.31
Chlorine	48.06	48.72	47.78	43.35	42.10	31.16	36.97	48.84

The ions here present which might tend to lower the agricultural and hence the commercial value of dried and ground kelp are limited to sodium and chlorine, but these same ions are to be found in large quantities in all of the high grade commercial potash salts with the exception of sulfate of potash.

Relative Potassium, Sodium and Chlorine Content of Various Commodities

	Potassium	Sodium	Chlorine
Macrocystis pyrifera	100	35.7	118.6
Nereocystis Luetkeana	100	33.8	125.2
Pelagophycus porra	100	24.8	117.6
Muriate of potash, 90–95% basis	100	5.8	99.9
Muriate of potash, 80–85% basis	100	13.0	111.2
Muriate of potash, 70–75% basis	100	21.5	123.2
Potash manure salts, 20% minimum	100	90.5	248.3
Potash manure salts, 30% minimum	100	40.4	165.2
Kainit	100	128.5	294.2
Carnallit	100	108.0	454.7
Sylvinit	100	154.3	337.8

It is at once evident that few of the commercial salts are in any way superior to dried and ground kelp in the matter of sodium and chlorine content. Of all of these commodities, it is seen that only the 90–95 per cent and the 80–85 per cent muriate are appreciably superior to kelps in that they are lower in their relative sodium content. Muriate of potash, 70–75 per cent, has a potassium-sodium ratio of the same order of magnitude as that of kelp, and all of the lower grades of commercial salts are distinctly inferior in this respect. The results of the comparison when we turn to chlorine are even more striking. The ratio of chlorine to potassium in the highest grade of muriate is of the same order of magnitude as that of kelp, and all of the other commercial potash salts contain a larger proportion of chlorine to potassium. About one-half million tons of kainit are used in this country annually, to say nothing of the other grades of potassium salts containing sodium and chlorine. Any objection to the use of kelp on the basis of sodium and chlorine could certainly be urged with more force against the use of kainit and with almost equal force against the use of the ordinary grades of muriate. In so far as its sodium and chlorine content is concerned, dried and ground kelp, therefore, is superior in agricultural value to the potassium salt, which is most largely used in this country.

If we abandon the comparative method and consider the chlorine content of kelp on its own merits, it may be stated that there is little evidence to show that potash in the form of muriate is inferior to other salts as a potash fertilizer when applied to crops in general, and data is also available tending to show that the same thing is true in

the case of potatoes, which have been largely cited as a crop which is injured by the presence of chlorine.[14] Evidently the only condition under which danger is to be anticipated from the use of kelp as a potash fertilizer is on those soils the soluble salt content of which already approaches the toxic limit. All such cases must of course be considered on their merits. The agricultural value per unit of the potash contained in dried and ground kelp must be considered to be superior to that of most of the commercial potash salts and but little inferior to those of the highest potash content.

Considered strictly from the plant food content, the following figures are of interest as indicating what is to be expected from kelp in various conditions of moisture content:

AVERAGE COMPOSITION OF HARVESTABLE KELP (MACROCYSTIS PYRIFERA)

	Percentage of Moisture	Percentage of Nitrogen	Percentage of Phosphoric Acid (P_2O_5)	Percentage of Potash (K_2O)
Fresh	86.41	.19	.10	1.82
Water free	....	1.41	.75	13.63
Air dry	16.0	1.18	.63	11.45

The air-dried kelp should contain on the average about 16 per cent of moisture. This is of course subject to fluctuations in the hygroscopic content of the atmosphere. Under highly unfavorable conditions in damp weather when the dry kelp is spread out it may absorb as high as 30 per cent of moisture, but loses this again as soon as the moisture content of the atmosphere falls. Air-dried kelp, therefore, contains approximately the same amount of potash as kainit, slightly more than 1 per cent of nitrogen, and about .6 of 1 per cent of phosphoric acid. Little is to be expected from kelp in so far as its phosphoric acid content is concerned. The value and limitations of the nitrogen have been studied by Stewart of this laboratory and reported elsewhere.[15] In view of all existing information, it seems fair to assign a commercial value to the constituents of kelp of about $3 per unit for nitrogen and 75 cents per unit for potash. The commercial value of air-dried kelp, then, should approximate $12 per ton and justify additional charges for freight at least equal to transportation charges on kainit. This requires that approximately 6.2 tons of fresh *Macrocystis* be harvested to furnish one ton of kelp worth approximately $12. Where this can be done at a profit the utilization of kelp will be a commercial success.

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[14] The Use and Value of Seaweed as Manure, by James Hendrick, Transactions of the Highland and Agricultural Society of Scotland, 5th Series, Vol. 10.

[15] Studies on the Availability of the Nitrogen in Pacific Coast Kelps, by G. R. Stewart, unpublished manuscript.

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